***DEPARTMENT OF THE INTERIOR***

***U.S. GEOLOGICAL SURVEY***

# Preliminary Results of a Precise Leveling Survey in Yellowstone National Park, Wyoming, September 1986

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## ABSTRACT

A precise leveling survey across the eastern part of Yellowstone Caldera in September 1986 revealed that 25 mm of subsidence had occurred since the previous survey in September 1985. The uplift that has been detected for 60 years by repeated surveys appears to have stopped, at least temporarily. A second leveling line across the western part of the caldera was observed for the first time since 1976; 170 mm of net uplift occurred along that line during 1976-1986.

Uplift in Yellowstone Caldera may accumulate over periods of decades to centuries interrupted by brief periods of relative quiesence or short-term subsidence.

## INTRODUCTION

Yellowstone National Park is located within the Yellowstone Plateau volcanic field, an extension of the Eastern Snake River Plain volcanic field (Fig. 1). The Yellowstone Plateau has erupted intermittently during the past 2.0 million years, most recently about 75,000 years ago. Rhyolite is the dominant eruptive product; it occurs as flows, domes, and voluminous ash-flow tuffs (Christiansen, 1984). A vigorous hydrothermal system in the Park is a surface manifestation of a heat source at depth, inferred to be a cooling body of rhyolite magma remnant from the last caldera-forming eruption 0.6 my ago. Contemporary ground deformation in Yellowstone Caldera provides insights into subsurface processes, and is an important input to help in assessments of volcanic hazards for future eruptions. For these reasons, precise leveling surveys throughout the Park have been carried out since 1923. This report summarizes results of a survey in September 1986, which was part of an annual deformation monitoring project begun in 1983 by the U.S. Geological Survey.

### Purpose and Scope

Precise leveling surveys from 1923 to 1976 in Yellowstone Caldera revealed a pattern of uplift centered along a northeast-trending axis between the Mallard Lake and Sour Creek resurgent domes (Pelton and Smith, 1979, 1982). The U.S. Geological Survey has conducted annual leveling surveys in Yellowstone National Park since 1983 (Dzurisin and Yamashita, 1986; Dzurisin and others, 1986). This project is supported by the Volcano Hazards Program and is focused on physical processes in large silicic magma bodies. One outcome of the project will be an assessment of volcanic hazards in Yellowstone National Park and the surrounding area. This report summarizes results of the September 1986 survey, and briefly discusses their implications. A more detailed discussion is given by Dzurisin and Yamashita (1987).

### Participants and Schedule

The 1986 leveling survey started on September 2nd and ended on September 17, 1986. Crew members included: Daniel Dzurisin, Bruce Furukawa, Steve Gustafson, Gary Stoopes, and Ken Yamashita (USGS Cascades Volcano Observatory); John Estrem (USGS Menlo Park); Mike Luessen, Tom Neace, and Kerry Rueblemann (Idaho State University). Two crews observed lines from Canyon Junction to Lake Butte and from Lewis Falls to Madison Junction (Fig.

2). The crews also spent two days leveling in the Missouri Flats area (about 8 km west of Hebgen Lake, Montana), in a cooperative project with Ross Stein (USGS Menlo Park).

## Procedures

Two leveling lines across Yellowstone Caldera were surveyed using two Wild NA-2 pendulum levels with micrometer plates. A collimation test was performed on both instruments at the start of each day's leveling. Wild N3 Spirit levels were used for the 1983-85 surveys and, because the Wild N3 is not susceptible to magnetic errors, no magnetic corrections were made for those surveys. However, tests have shown that NA-2 levels are subject to systematic magnetic errors, so a linear correction of 0.1 x L mm, where L is the magnetic-north component of distance in kilometers along the leveling line, was applied to the 1986 data (Tables 1 & 3). This correction is based on the results of Rumpf and Meurisch (1981), who tested various automatic levels in the field and laboratory. Two sets of Wild GPLE-3 Invar 3-meter rods were used; both were calibrated by the National Bureau of Standards to an accuracy of (0.000015 + 0.000005 x h) meters, where h is the height of each 1-cm graduation above the bottom of the rod. Rod readings were recorded in the field with a Hewlett-Packard 41-C calculator, programmed to reject differences larger than 0.10 mm between right-side and left-side rod readings. Virtually all readings were above the 50 cm portion of the rod. Temperatures to 1 degree Fahrenheit were recorded at the 50 and 250 cm height at each rod for every set-up. P-K nails pounded into the pavement served as temporary turning points for each set-up. All sections were single-run in opposing directions to offset any errors introduced by pin settling. A critical section of the Lewis Falls line, between West Thumb and the Mallard Lake resurgent dome, was double-run as a check on procedures.

## Lewis Falls Leveling Line

In September 1986, the leveling line from Lewis Falls to Madison Junction (Figs. 6-8) in the western part of the caldera was observed for the first time since 1976. The line follows in part the one established in 1923, but portions of that line are on roads now abandoned by the Park Service. As now measured, the Lewis Falls leveling line starts 0.3 km south of Lewis Falls and follows paved National Park Service roads north over Craig Pass, past the Old Faithful area to the bridge over the Gibbon River, just south of Madison Junction (see Fig. 2). The 1986 crew installed fourteen new benchmarks from Lewis Falls to Shoshone Lake to replace benchmarks along abandoned roads and to shorten distances between existing benchmarks. Descriptions of all benchmarks along the line are given in the Appendix. The Lewis Falls leveling line is approximately 75 km long (road length, 46 km long as the crow flies). It spans the width of the caldera in a northwesterly direction and crosses the base of the Mallard Lake resurgent dome. Together with the Canyon Junction line (Fig. 9), the Lewis Falls line provides a useful short-term monitor of caldera-wide deformation to supplement larger surveys measured less frequently.
(Descriptions for benchmarks along the eastern line from Lake Butte to Canyon junction are contained in Dzurisin and others (1986).

## EARLIER WORK

At least 726 mm of uplift, at an average rate of 14 mm/yr, occurred in Yellowstone Caldera between leveling surveys in 1923 and 1976 (Pelton and Smith, 1979,1982). Uplift was centered along a northeast-trending axis that connects the Sour Creek and Mallard Lake resurgent domes (Fig. 2). In October 1983, members of the Cascades Volcano Observatory (CVO) re-observed 24 km (all double-run) of the Canyon Junction line, in the eastern part of the caldera, from Trout Lake to Indian Pond (Fig. 9). An additional uplift of 162 mm was detected near LeHardy Rapids (benchmark DA 3 1934) since the 1976 survey (Dzurisin and Yamashita, 1986). In September 1984, the entire Canyon Junction line was releveled and sections not leveled in 1983 were double-run. Again the maximum uplift was near LeHardy Rapids; an additional 17 mm of uplift had occurred since the 1983 survey (Table 2 and Fig. 5). Thus the uplift from 1976 to 1984 was 179 mm and the average rate of uplift for 1976-1984 was 23 mm/yr (Dzurisin and others, 1986). In 1985, when the CVO crew releveled the Canyon Junction line, it was stable within the detection limit of the instruments (Table 2, Fig. 5). This result was consistent with a trilateration survey established in 1984 and re-observed in 1985, which also detected no significent changes (Dzurisin and others, 1986).

## 1986 RESULTS

From September 1985 to September 1986, the eastern line (Canyon Junction line) subsided by 25.5 mm at benchmark DA 3 1934, near the former center of uplift (Table 2). The subsidence, as with the uplift, is generally symmetric about the LeHardy Rapids area (Fig. 5). Symmetrical deformation has been noted in the annual surveys (1983-86) and the larger surveys reported by Pelton and Smith (Fig. 2-5). No significant cross-caldera tilt has been detected in the eastern line since surveys began in 1923.

During 1976-1986, the western line (Lewis Falls level line) uplifted 169.8 mm at benchmark 51 MDC (2 km southwest of Isa Lake) with respect to N 13 1923 (near Lewis Falls on the southern caldera rim) (Table 4 and Figs. 2 & 4). Benchmark 51 MDC is close to the center of uplift identified by Pelton and Smith (1979, 1982). The total uplift along the western line from 1923 to 1986 is 789 mm as measured at benchmark H 10 1923 (Table 4). The average rate of uplift for 1976-86 is 17 mm/yr compared to 14 mm/yr for 1923-76, so the rate seems to have increased approximately 20% in the past decade. The western line has a steep southern segment between West Thumb and the Mallrad Lake resurgent dome and an asymmetrical shape about the axis of uplift. Also the western profile, unlike the eastern profile, includes a regional southward tilt across the caldera. The Madison Junction end of the line (USBPR 6802) uplifted 62.6 mm with respect to N 13 1923 at Lewis Falls during 1976-86. The southward tilt and asymmetrical shape were also noted in the 1923-76 surveys (Fig. 4).

## DISCUSSION

In the eastern part of Yellowstone Caldera, annual surveys since 1983 suggest accelerated uplift from 1976-84, compared to the 1923-76 results, quiesence in 1985, and subsidence in 1986. The western part of the caldera had accelerated uplift during 1976-86 compared to 1923-76. Because 1986 is the first survey along the western line in a decade, it is not known whether

the quiesence and subsidence detected along the eastern line in 1985 and 1986, respectively, were a caldera-wide phenomenon. If so, maximum uplift along the western line between 1976 and 1984 was greater than the 170 mm reported here. It then follows that the 17 mm/yr rate for the western line during 1976-86 could be higher (1-3mm/yr) during 1976-1984. These qualifications should be kept in mind when reviewing the figures and tables in this report.

Several conclusions can be drawn from the data now available. First, uplift has continued since 1976 at rates comparable to or slightly higher than those during 1923-1976. Second, there is a strong suggestion that uplift accumulates episodically, interrupted on occasion by periods of subsidence or quiescence. Finally, Yellowstone Caldera, with its active hydrothermal system, recent volcanism, and continued seismicity, is a region of constant change. Continued deformation in the caldera reflects this state of flux and emphasizes that processes in the crust are probably as dynamic as their surface manifestations. If a sudden change were to take place in the inferred magma body beneath Yellowstone Caldera, deformation monitoring would provide important input to assessments of changing volcanic hazards, especially in conjunction with other parameters (i.e., changing seismicity or hydrothermal activity). For this reason, we propose to continue annual leveling surveys at Yellowstone for the foreseeable future. In this way the deformation patterns in Yellowstone Caldera can be well characterized and better understood.

## ACKNOWLEDGEMENTS

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TABLE 1

Benchmark Elevations 1923 - 1986

Lake Butte - Canyon Junction

| BENCHMARK NAME | ROAD DISTANCE (KM) | PROJECTED DISTANCE (KM MN) | ELEVATION 1923 (M) | ELEVATION 1976 (M) | ELEVATION 1983 (M) | ELEVATION 1984 (M) | ELEVATION 1985 (M) | ELEVATION 1986 OBS (M) | ELEVATION 1986 MAG (M) |
|---|---|---|---|---|---|---|---|---|---|
| 36 MDC 1976 | 0.0 | 0.0 | - | 2545.6183 | 2545.6183 | 2545.6183 | 2545.6183 | 2545.6183 | 2545.6183 |
| CVO 84-21 | 0.7 | 0.0 | - | - | - | 2547.1431 | 2547.1418 | 2547.1418 | 2547.1418 |
| CVO 84-28 | 1.5 | 0.3 | - | - | - | - | - | 2500.7829 | 2500.7830 |
| 35 MDC 1976 | 1.6 | 0.3 | - | 2492.5972 | - | - | - | - | - |
| CVO 84-20 | 2.3 | -0.3 | - | - | - | 2465.6213 | 2465.6226 | 2465.6211 | 2465.6211 |
| CVO 84-26 | 3.3 | -0.7 | - | - | - | 2437.8181 | 2437.8198 | 2437.8190 | 2437.8189 |
| F12 1923 | 3.5 | 0.7 | 2475.939 | 2475.9292 | - | - | - | - | - |
| CVO 84-25 | 4.7 | -0.6 | - | - | - | 2379.1235 | 2379.1270 | 2379.1235 | 2379.1235 |
| CVO 84-24 | 5.3 | 0.3 | - | - | - | 2360.5466 | 2360.5491 | 2360.5437 | 2360.5438 |
| CVO 84-19 | 6.2 | 0.9 | - | - | - | 2360.5254 | 2360.5298 | 2360.5236 | 2360.5237 |
| E12 1923 | 6.9 | 3.4 | 2425.062 | 2425.1851 | - | - | - | - | - |
| CVO 84-18 | 7.4 | 1.2 | - | - | - | 2376.9187 | 2376.9220 | 2376.9143 | 2376.9144 |
| CVO 84-14 | 8.2 | 1.4 | - | - | - | 2366.0044 | 2366.0080 | 2366.0006 | 2366.0007 |
| 34 MDC 1976 | 8.7 | 4.0 | - | 2411.7201 | - | - | - | - | - |
| CVO 84-13 | 9.4 | 2.2 | - | - | - | 2358.8972 | 2358.9045 | 2358.8929 | 2358.8931 |
| D12 1923 | 9.9 | 4.7 | 2436.893 | 2437.1036 | - | - | - | - | - |
| CVO 84-17 | 10.6 | 3.1 | - | - | - | 2358.3665 | 2358.3740 | 2358.3605 | 2358.3608 |
| CVO 84-16 | 11.6 | 3.4 | - | - | - | 2359.2473 | 2359.2550 | 2359.2382 | 2359.2385 |
| 33 MDC 1976 | 11.9 | 4.0 | - | 2381.6153 | - | - | - | - | - |
| CVO 84-27 | 12.9 | 3.8 | - | - | - | - | 2376.1045 | 2376.0835 | 2376.0838 |
| CVO 84-12 | 12.9 | 3.8 | - | - | - | 2371.9861 | 2371.9927 | - | - |
| 32 MDC 1976 | 14.0 | 3.3 | - | 2366.0016 | 2366.0853 | 2366.0959 | 2366.1018 | 2366.0801 | 2366.0804 |
| CVO 84-15 | 14.5 | 3.1 | - | - | - | 2362.2903 | 2362.2969 | 2362.2729 | 2362.2733 |
| USBPR7743 | 15.7 | 2.8 | - | 2360.4440 | 2360.5420 | 2360.5535 | 2360.5570 | 2360.5346 | 2360.5349 |
| 31 MDC 1976 | 17.0 | 2.9 | - | 2363.8227 | 2363.9341 | 2363.9453 | 2363.9467 | 2363.9215 | 2363.9218 |
| CVO 84-23 | 18.2 | 3.0 | - | - | - | 2374.4888 | 2374.4901 | 2374.4630 | 2374.4633 |
| A11 1923 | 18.2 | 3.0 | 2374.721 | 2375.3398 | 2375.4705 | 2375.4822 | 2375.4814 | - | - |
| L19 1977 | 19.1 | 3.7 | - | - | - | 2395.1367 | 2395.1376 | 2395.1101 | 2395.1105 |
| 30 MDC 1976 | 19.6 | 4.1 | - | 2390.2493 | 2390.3848 | 2390.3977 | 2390.3972 | 2390.3708 | 2390.3712 |
| CVO 85-220 | 20.3 | 4.8 | - | - | - | - | 2380.6717 | 2380.6452 | 2380.6457 |
| CVO 84-11 | 20.3 | 4.8 | - | - | - | 2380.6475 | 2380.6462 | - | - |
| B11 1923 | 21.2 | 5.6 | 2365.034 | 2365.7604 | 2365.9075 | 2365.9248 | 2365.9236 | 2365.8970 | 2365.8976 |
| CVO 85-221 | 22.1 | 6.2 | - | - | - | - | 2362.9143 | 2362.8874 | 2362.8880 |
| CVO 84-10 | 22.1 | 6.2 | - | - | - | 2362.8496 | 2362.8486 | - | - |
| 29 MDC 1976 | 22.9 | 7.1 | - | 2368.5925 | 2368.7529 | 2368.7695 | 2368.7706 | 2368.7439 | 2368.7446 |
| DA 3 1934 | 23.4 | 7.1 | - | 2353.1317 | 2353.2937 | 2353.3108 | 2353.3111 | 2353.2849 | 2353.2856 |
| 28 MDC 1976 | 24.3 | 7.1 | - | 2359.0792 | 2359.2385 | 2359.2585 | 2359.2576 | 2359.2322 | 2359.2329 |
| CVO 85-222 | 25.1 | 7.1 | - | - | - | - | 2350.5687 | 2350.5430 | 2350.5437 |
| CVO 84-9 | 25.1 | 7.1 | - | - | - | 2350.7136 | 2350.7128 | - | - |
| 27 MDC 1976 | 26.4 | 7.6 | - | 2351.0709 | 2351.2251 | 2351.2476 | 2351.2464 | 2351.2228 | 2351.2236 |
| CVO 85-223 | 27.3 | 7.8 | - | - | - | - | 2354.4310 | 2354.4107 | 2354.4114 |
| CVO 84-8 | 27.3 | 7.8 | - | - | - | 2354.3914 | 2354.3899 | - | - |
| CVO 84-22 | 28.6 | 8.4 | - | - | - | 2363.6130 | 2363.6098 | 2363.5907 | 2363.5915 |
| 26 MDC 1976 | 28.6 | 8.4 | - | 2364.1762 | 2364.3401 | 2364.3606 | 2364.3660 | - | - |
| CVO 85-224 | 29.5 | 8.6 | - | - | - | - | 2369.6239 | 2369.6027 | 2369.6036 |
| CVO 84-7 | 29.5 | 8.6 | - | - | - | 2369.5935 | 2369.5951 | - | - |

TABLE 1 (cont.)

| BENCHMARK NAME | ROAD DISTANCE (KM) | PROJECTED DISTANCE (KM MN) | ELEVATION 1923 (M) | ELEVATION 1976 (M) | ELEVATION 1983 (M) | ELEVATION 1984 (M) | ELEVATION 1985 (M) | ELEVATION 1986 OBS (M) | ELEVATION 1986 MAG (M) |
|---|---|---|---|---|---|---|---|---|---|
| E11 A2 | 30.3 | 9.1 | - | 2344.8323 | 2344.9568 | 2344.9790 | 2344.9774 | 2344.9557 | 2344.9566 |
| F11 A | 31.1 | 9.6 | - | 2343.5588 | 2343.6743 | 2343.6973 | 2343.6941 | 2343.6740 | 2343.6750 |
| CVO 85-225 | 32.1 | 10.3 | - | - | - | - | 2343.2893 | 2343.2677 | 2343.2687 |
| CVO 84-5 | 32.1 | 10.3 | - | - | - | 2343.2456 | 2343.2460 | - | - |
| CVO 85-226 | 33.2 | 11.3 | - | - | - | - | 2345.0752 | 2345.0563 | 2345.0574 |
| CVO 84-4 | 33.2 | 11.3 | - | - | - | 2345.1052 | 2345.1038 | - | - |
| G11 1923 | 33.5 | 11.2 | 2358.208 | 2358.6691 | - | - | - | - | - |
| CVO 85-227 | 34.0 | 11.7 | - | - | - | - | 2369.9107 | 2369.8933 | 2369.8945 |
| CVO 84-6 | 34.0 | 11.7 | - | - | - | 2369.8560 | 2369.8504 | - | - |
| CVO 84-3 | 34.9 | 12.1 | - | - | - | 2341.2048 | 2341.1995 | - | - |
| CVO 85-228 | 34.9 | 12.1 | - | - | - | - | 2341.2150 | 2341.1983 | 2341.1995 |
| 25 MDC 1976 | 35.5 | 12.3 | - | 2340.8244 | - | 2340.8975 | 2340.8927 | 2340.8751 | 2340.8763 |
| CVO 85-229 | 36.7 | 12.8 | - | - | - | - | 2342.0763 | 2342.0584 | 2342.0597 |
| CVO 84-2 | 36.7 | 12.8 | - | - | - | 2342.0845 | 2342.0807 | - | - |
| 24 MDC 1976 | 37.4 | 13.4 | - | 2344.9191 | - | 2344.9592 | 2344.9564 | 2344.9383 | 2344.9396 |
| 23 MDC 1976 | 38.8 | 14.4 | - | 2340.4325 | - | 2340.4609 | 2340.4597 | 2340.4396 | 2340.4410 |
| 22 MDC 1976 | 39.5 | 15.2 | - | 2346.2685 | - | 2346.2927 | 2346.2930 | 2346.2721 | 2346.2736 |
| LC 58 1977 | 40.6 | 16.1 | - | - | - | 2366.0410 | 2366.0399 | 2366.0194 | 2366.0210 |
| J11 1923 | 41.5 | 16.5 | 2377.327 | 2377.5324 | - | 2377.5525 | 2377.5532 | 2377.5315 | 2377.5332 |
| CVO 85-230 | 42.2 | 17.3 | - | - | - | - | 2413.2915 | 2413.2669 | 2413.2687 |
| CVO 84-1 | 42.2 | 17.3 | - | - | - | 2413.1499 | 2413.1469 | - | - |
| 11 MDC 1976 | 43.3 | 18.4 | - | 2413.0200 | - | 2413.0373 | 2413.0411 | 2413.0173 | 2413.0191 |

TABLE 2

Elevation Changes 1923 - 1986

Lake Butte - Canyon Junction

| BENCHMARK NAME | ROAD DISTANCE (KM) | CHANGE 1923-1976 (MM) | CHANGE 1923-1986 (MM) | CHANGE 1976-1986 (MM) | CHANGE 1983-1984 (MM) | CHANGE 1984-1985 (MM) | CHANGE 1985-1986 (MM) |
|---|---|---|---|---|---|---|---|
| 36 MDC 1976 | 0.0 | - | - | 0.0 | 0.0 | 0.0 | 0.0 |
| CVO 84-21 | 0.7 | - | - | - | - | -1.3 | 0.0 |
| CVO 84-28 | 1.5 | - | - | - | - | - | - |
| 35 MDC 1976 | 1.6 | - | - | - | - | - | - |
| CVO 84-20 | 2.3 | - | - | - | - | 1.3 | -1.5 |
| CVO 84-26 | 3.3 | - | - | - | - | 1.7 | -0.9 |
| F12 1923 | 3.5 | -10 | - | - | - | - | - |
| CVO 84-25 | 4.7 | - | - | - | - | 3.5 | -3.5 |
| CVO 84-24 | 5.3 | - | - | - | - | 2.5 | -5.3 |
| CVO 84-19 | 6.2 | - | - | - | - | 4.4 | -6.1 |
| E12 1923 | 6.9 | 123 | - | - | - | - | - |
| CVO 84-18 | 7.4 | - | - | - | - | 3.3 | -7.7 |
| CVO 84-14 | 8.2 | - | - | - | - | 3.6 | -7.3 |
| 34 MDC 1976 | 8.7 | - | - | - | - | - | - |
| CVO 84-13 | 9.4 | - | - | - | - | 7.3 | -11.3 |
| D12 1923 | 9.9 | 210 | - | - | - | - | - |
| CVO 84-17 | 10.6 | - | - | - | - | 7.5 | -13.2 |
| CVO 84-16 | 11.6 | - | - | - | - | 7.7 | -16.5 |
| 33 MDC 1976 | 11.9 | - | - | - | - | - | - |
| CVO 84-27 | 12.9 | - | - | - | - | - | -20.7 |
| CVO 84-12 | 12.9 | - | - | - | - | 6.6 | - |
| 32 MDC 1976 | 14.0 | - | - | 78.8 | 10.6 | 5.9 | -21.3 |
| CVO 84-15 | 14.5 | - | - | - | - | 6.6 | -23.6 |
| USBPR7743 | 15.7 | - | - | 90.9 | 11.5 | 3.5 | -22.2 |
| 31 MDC 1976 | 17.0 | - | - | 99.1 | 11.2 | 1.4 | -25.0 |
| CVO 84-23 | 18.2 | - | - | - | - | 1.3 | -26.7 |
| A11 1923 | 18.2 | 619 | - | - | 11.7 | -0.8 | - |
| L19 1977 | 19.1 | - | - | - | - | 0.9 | -27.1 |
| 30 MDC 1976 | 19.6 | - | - | 121.9 | 12.9 | -0.5 | -26.0 |
| CVO 85-220 | 20.3 | - | - | - | - | - | -26.0 |
| CVO 84-11 | 20.3 | - | - | - | - | -1.3 | - |
| B11 1923 | 21.2 | 726 | 863 | 137.2 | 17.3 | -1.2 | -26.0 |
| CVO 85-221 | 22.1 | - | - | - | - | - | -26.3 |
| CVO 84-10 | 22.1 | - | - | - | - | -1.0 | - |
| 29 MDC 1976 | 22.9 | - | - | 152.1 | 16.6 | 1.1 | -26.0 |
| DA 3 1934 | 23.4 | - | - | 153.9 | 17.1 | 0.3 | -25.5 |
| 28 MDC 1976 | 24.3 | - | - | 153.7 | 20.0 | -0.9 | -24.7 |
| CVO 85-222 | 25.1 | - | - | - | - | - | -25.0 |
| CVO 84-9 | 25.1 | - | - | - | - | -0.8 | - |
| 27 MDC 1976 | 26.4 | - | - | 152.6 | 22.5 | -1.2 | -22.8 |
| CVO 85-223 | 27.3 | - | - | - | - | - | -19.5 |
| CVO 84-8 | 27.3 | - | - | - | - | -1.5 | - |
| CVO 84-22 | 28.6 | - | - | - | - | -3.2 | -18.3 |
| 26 MDC 1976 | 28.6 | - | - | - | 20.5 | 5.4 | - |
| CVO 85-224 | 29.5 | - | - | - | - | - | -20.4 |
| CVO 84-7 | 29.5 | - | - | - | - | 1.6 | - |

TABLE 2 (cont.)

| BENCHMARK NAME | ROAD DISTANCE (KM) | CHANGE 1923-1976 (MM) | CHANGE 1923-1986 (MM) | CHANGE 1976-1986 (MM) | CHANGE 1983-1984 (MM) | CHANGE 1984-1985 (MM) | CHANGE 1985-1986 (MM) |
|---|---|---|---|---|---|---|---|
| E11 A2 | 30.3 | - | - | 124.3 | 22.2 | -1.6 | -20.8 |
| F11 A | 31.1 | - | - | 116.2 | 23.0 | -3.2 | -19.2 |
| CVO 85-225 | 32.1 | - | - | - | - | - | -20.6 |
| CVO 84-5 | 32.1 | - | - | - | - | 0.4 | - |
| CVO 85-226 | 33.2 | - | - | - | - | - | -17.8 |
| CVO 84-4 | 33.2 | - | - | - | - | -1.4 | - |
| G11 1923 | 33.5 | 461 | - | - | - | - | - |
| CVO 85-227 | 34.0 | - | - | - | - | - | -16.3 |
| CVO 84-6 | 34.0 | - | - | - | - | -5.6 | - |
| CVO 84-3 | 34.9 | - | - | - | - | -5.3 | - |
| CVO 85-228 | 34.9 | - | - | - | - | - | -15.5 |
| 25 MDC 1976 | 35.5 | - | - | 51.9 | - | -4.8 | -16.4 |
| CVO 85-229 | 36.7 | - | - | - | - | - | -16.7 |
| CVO 84-2 | 36.7 | - | - | - | - | -3.8 | - |
| 24 MDC 1976 | 37.4 | - | - | 20.5 | - | -2.8 | -16.8 |
| 23 MDC 1976 | 38.8 | - | - | 8.5 | - | -1.2 | -18.7 |
| 22 MDC 1976 | 39.5 | - | - | 5.1 | - | 0.3 | -19.4 |
| LC 58 1977 | 40.6 | - | - | - | - | -1.1 | -18.9 |
| J11 1923 | 41.5 | 206 | 206 | 0.8 | - | 0.7 | -20.0 |
| CVO 85-230 | 42.2 | - | - | - | - | - | -22.9 |
| CVO 84-1 | 42.2 | - | - | - | - | -3.0 | - |
| 11 MDC 1976 | 43.3 | - | - | -0.9 | - | 3.8 | -22.0 |

TABLE 3

Benchmark Elevations 1923 - 1986

Lewis Falls - Madison Junction

| BENCHMARK NAME | ROAD DISTANCE (KM) | PROJECTED DISTANCE (KM MN) | ELEVATION 1923 (M) | ELEVATION 1976 (M) | ELEVATION 1986 OBS (M) | ELEVATION 1986 MAG (M) | BENCHMARK NAME |
|---|---|---|---|---|---|---|---|
| N 13 1923 | 0.0 | 0.0 | 2359.522 | 2359.4958 | 2359.4958 | 2359.4958 | N 13 1923 |
| CVO 86-10 | 1.0 | 1.0 | - | - | 2362.2747 | 2362.2748 | CVO 86-10 |
| M 13 1923 | 2.4 | 2.2 | 2379.232 | 2379.2079 | 2379.2083 | 2379.2085 | M 13 1923 |
| 10 MDC 1976 | 4.3 | 3.7 | - | 2375.2212 | 2375.2219 | 2375.2223 | 10 MDC 1976 |
| L 13 1923 | 5.8 | 4.8 | 2373.400 | 2373.4242 | 2373.4262 | 2373.4267 | L 13 1923 |
| CVO 86-11 | 6.6 | 5.6 | - | - | 2372.3678 | 2372.3683 | CVO 86-11 |
| USBPR NONE | 7.7 | 6.5 | - | 2374.2670 | 2374.2690 | 2374.2697 | USBPR NONE |
| K 13 1923 | 9.2 | 7.1 | 2378.216 | 2378.2820 | - | - | K 13 1923 |
| CVO 86-12 | 9.3 | 8.1 | - | - | 2408.5395 | 2408.5403 | CVO 86-12 |
| CVO 86-13 | 11.1 | 9.7 | - | - | 2415.8130 | 2415.8139 | CVO 86-13 |
| CVO 86-14 | 12.6 | 10.9 | - | - | 2431.9514 | 2431.9525 | CVO 86-14 |
| J 13 1923 | 13.3 | 10.4 | 2406.787 | 2406.9476 | - | - | J 13 1923 |
| CVO 86-15 | 14.0 | 12.4 | - | - | 2425.3713 | 2425.3726 | CVO 86-15 |
| CVO 86-16 | 15.5 | 13.8 | - | - | 2419.5525 | 2419.5539 | CVO 86-16 |
| H 13 1923 | 15.6 | 12.1 | 2428.752 | 2428.8930 | - | - | H 13 1923 |
| GV2 1977 | 16.8 | 15.1 | - | - | 2392.5939 | 2392.5954 | GV2 1977 |
| G 13 1923 | 17.7 | 13.9 | 2413.465 | 2413.6380 | - | - | G 13 1923 |
| 9 MDC 1977 | 18.6 | 16.6 | - | 2373.3888 | 2373.4142 | 2373.4158 | 9 MDC 1977 |
| 54 MDC 1976 | 19.9 | 17.6 | - | 2378.4938 | 2378.5434 | 2378.5452 | 54 MDC 1976 |
| 53 MDC 1976 | 22.0 | 17.7 | - | 2462.4371 | 2462.5550 | 2462.5567 | 53 MDC 1976 |
| CVO 86-17 | 23.9 | 17.3 | - | - | 2508.5106 | 2508.5123 | CVO 86-17 |
| P 10 1923 | 24.7 | 18.0 | 2507.719 | 2508.1657 | - | - | P 10 1923 |
| CVO 86-18 | 25.6 | 17.6 | - | - | 2525.4765 | 2525.4783 | CVO 86-18 |
| O 10 1923 | 26.9 | 18.8 | 2549.612 | 2550.1824 | - | - | O 10 1923 |
| 10-34 1986 | 27.4 | 17.7 | - | - | 2549.8946 | 2549.8964 | 10-34 1986 |
| CVO 86-19 | 27.4 | 17.7 | - | - | 2550.2989 | 2550.3006 | CVO 86-19 |
| N 10 1923 | 28.4 | 19.6 | 2536.108 | 2536.7210 | - | - | N 10 1923 |
| CVO 86-20 | 28.8 | 17.1 | - | - | 2594.6713 | 2594.6730 | CVO 86-20 |
| CVO 86-21 | 30.4 | 17.0 | - | - | 2553.7815 | 2553.7832 | CVO 86-21 |
| CVO 86-22 | 31.3 | 17.7 | - | - | 2534.6226 | 2534.6244 | CVO 86-22 |
| CVO 86-23 | 32.7 | 18.4 | - | - | 2458.1475 | 2458.1493 | CVO 86-23 |
| M 10 1923 | 32.7 | 19.5 | 2465.702 | 2466.3855 | - | - | M 10 1923 |
| 10-35 1986 | 34.2 | 18 | - | - | 2461.0699 | 2461.0717 | 10-35 1986 |
| 52 MDC 1976 | 34.3 | 18.1 | - | 2461.0500 | 2461.2139 | 2461.2157 | 52 MDC 1976 |
| L 10 1937 R | 35.8 | 17.7 | - | 2443.2922 | 2443.4577 | 2443.4595 | L 10 1937 R |
| K 10 1936 R | 37.1 | 16.8 | - | 2518.3277 | 2518.4942 | 2518.4959 | K 10 1936 R |
| 51 MDC 1976 | 39.0 | 15.8 | - | 2456.9446 | 2457.1129 | 2457.1144 | 51 MDC 1976 |
| H 10 1923 | 41.1 | 14.8 | 2413.750 | 2414.3816 | 2414.5368 | 2414.5383 | H 10 1923 |
| 50 MDC 1976 | 42.6 | 14.4 | - | 2394.4503 | 2394.6005 | 2394.6020 | 50 MDC 1976 |
| 49 MDC 1976 | 44.2 | 14.3 | - | 2378.8232 | 2378.9714 | 2378.9728 | 49 MDC 1976 |
| OF 9 1976 | 45.6 | 15.1 | - | - | 2325.7067 | 2325.7082 | OF 9 1976 |
| F 10 1923 | 45.8 | 15.1 | 2311.050 | 2311.6486 | 2311.7901 | 2311.7916 | F 10 1923 |
| USBPR 7389 | 47.5 | 16.1 | - | 2252.6360 | - | - | USBPR 7389 |
| NPS A 19 | 47.5 | 16.1 | - | - | 2254.2101 | 2254.2117 | NPS A 19 |
| 10-1 1986 | 49.0 | 16.2 | - | - | 2237.1135 | 2237.1151 | 10-1 1986 |
| OF 4 1976 | 49.9 | 16.2 | - | 2237.5477 | 2237.6679 | 2237.6695 | OF 4 1976 |

TABLE 3 (cont.)

| BENCHMARK NAME | ROAD DISTANCE (KM) | PROJECTED DISTANCE (KM MN) | ELEVATION 1923 (M) | ELEVATION 1976 (M) | ELEVATION 1986 OBS (M) | ELEVATION 1986 MAG (M) | BENCHMARK NAME |
|---|---|---|---|---|---|---|---|
| 10-2 1986 | 49.9 | 16.1 | - | - | 2237.4209 | 2237.4225 | 10-2 1986 |
| 48 MDC 1976 | 51.2 | 16.6 | - | 2222.1473 | 2222.2583 | 2222.2600 | 48 MDC 1976 |
| USBPR 7273 | 52.9 | 17.8 | - | 2216.9964 | 2217.1121 | 2217.1139 | USBPR 7273 |
| D 10 1923 | 54.7 | 17.6 | 2236.260 | 2236.7392 | - | - | D 10 1923 |
| 47 MDC 1976 | 55.2 | 20.0 | - | 2216.7213 | 2216.8381 | 2216.8401 | 47 MDC 1976 |
| DA 3 1935 | 57.0 | 21.7 | - | 2211.2259 | 2211.3386 | 2211.3407 | DA 3 1935 |
| 46 MDC 1976 | 58.4 | 22.6 | - | 2207.1676 | 2207.2738 | 2207.2760 | 46 MDC 1976 |
| C 10 1923 | 58.5 | 21.7 | 2205.581 | 2206.0695 | - | - | C 10 1923 |
| 45 MDC 1976 | 60.0 | 23.8 | - | 2207.9219 | 2208.0193 | 2208.0217 | 45 MDC 1976 |
| 44 MDC 1976 | 61.9 | 25.3 | - | 2217.5609 | 2217.6630 | 2217.6656 | 44 MDC1976 |
| 43 MDC 1976 | 62.7 | 26.8 | - | 2211.3440 | 2211.4351 | 2211.4377 | 43 MDC 1976 |
| DA 1 1934 | 65.1 | 28.2 | - | 2187.8870 | 2187.9655 | 2187.9683 | DA 1 1934 |
| 42 MDC 1976 | 66.8 | 29.4 | - | 2183.4245 | 2183.5002 | 2183.5032 | 42 MDC 1976 |
| Z 9 1923 | 68.4 | 30.6 | 2180.207 | 2180.5151 | 2180.5874 | 2180.5904 | Z 9 1923 |
| 41 MDC 1976 | 70.0 | 31.3 | - | 2173.1373 | 2173.2073 | 2173.2104 | 41 MDC 1976 |
| Y 9 1923 | 71.4 | 32.1 | 2164.809 | 2165.1261 | 2165.1945 | 2165.1977 | Y 9 1923 |
| 40 MDC 1976 | 73.1 | 33.4 | - | 2143.0528 | 2143.1165 | 2143.1198 | 40 MDC 1976 |
| E339 | 73.9 | 34.2 | - | - | 2118.0804 | 2118.0838 | E339 |
| USBPR 6802 | 74.7 | 34.4 | - | 2073.2197 | 2073.2789 | 2073.2823 | USBPR 6802 |

TABLE 4

Elevation Changes 1923 - 1986

Lewis Falls - Madison Junction

| BENCHMARK NAME | ROAD DISTANCE (KM) | CHANGE 1923-1976 (MM) | CHANGE 1923-1986 (MM) | CHANGE 1976-1986 (MM) |
|---|---|---|---|---|
| N 13 1923 | 0.0 | -26 | -26 | 0.0 |
| CVO 86-10 | 1.0 | - | - | - |
| M 13 1923 | 2.4 | -24 | -23 | 0.6 |
| 10 MDC 1976 | 4.3 | - | - | 1.1 |
| L 13 1923 | 5.8 | 24 | 27 | 2.5 |
| CVO 86-11 | 6.6 | - | - | - |
| USBPR NONE | 7.7 | - | - | 2.6 |
| K 13 1923 | 9.2 | 66 | - | - |
| CVO 86-12 | 9.3 | - | - | - |
| CVO 86-13 | 11.1 | - | - | - |
| CVO 86-14 | 12.6 | - | - | - |
| J 13 1923 | 13.3 | 161 | - | - |
| CVO 86-15 | 14.0 | - | - | - |
| CVO 86-16 | 15.5 | - | - | - |
| H 13 1923 | 15.6 | 141 | - | - |
| GV2 1977 | 16.8 | - | - | - |
| G 13 1923 | 17.7 | 173 | - | - |
| 9 MDC 1977 | 18.6 | - | - | 27.0 |
| 54 MDC 1976 | 19.9 | - | - | 51.4 |
| 53 MDC 1976 | 22.0 | - | - | 119.6 |
| CVO 86-17 | 23.9 | - | - | - |
| P 10 1923 | 24.7 | 447 | - | - |
| CVO 86-18 | 25.6 | - | - | - |
| O 10 1923 | 26.9 | 570 | - | - |
| 10-34 1986 | 27.4 | - | - | - |
| CVO 86-19 | 27.4 | - | - | - |
| N 10 1923 | 28.4 | 613 | - | - |
| CVO 86-20 | 28.8 | - | - | - |
| CVO 86-21 | 30.4 | - | - | - |
| CVO 86-22 | 31.3 | - | - | - |
| CVO 86-23 | 32.7 | - | - | - |
| M 10 1923 | 32.7 | 684 | - | - |
| 10-35 1986 | 34.2 | | | |
| 52 MDC 1976 | 34.3 | - | - | 165.7 |
| L 10 1937 R | 35.8 | - | - | 167.3 |
| K 10 1936 R | 37.1 | - | - | 168.2 |
| 51 MDC 1976 | 39.0 | - | - | 169.8 |
| H 10 1923 | 41.1 | 632 | 789 | 156.7 |
| 50 MDC 1976 | 42.6 | - | - | 151.7 |
| 49 MDC 1976 | 44.2 | - | - | 149.6 |
| OF 9 1976 | 45.6 | - | - | - |
| F 10 1923 | 45.8 | 599 | 742 | 143.0 |
| USBPR 7389 | 47.5 | - | - | - |
| NPS A 19 | 47.5 | - | - | - |
| 10-1 1986 | 49.0 | - | - | - |
| OF 4 1976 | 49.9 | - | - | 121.8 |

TABLE 4 (cont.)

| BENCHMARK NAME | ROAD DISTANCE (KM) | CHANGE 1923-1976 (MM) | CHANGE 1923-1986 (MM) | CHANGE 1976-1986 (MM) |
|---|---|---|---|---|
| 10-2 1986 | 49.9 | - | - | - |
| 48 MDC 1976 | 51.2 | - | - | 112.7 |
| USBPR 7273 | 52.9 | - | - | 117.5 |
| D 10 1923 | 54.7 | 479 | - | - |
| 47 MDC 1976 | 55.2 | - | - | 118.8 |
| DA 3 1935 | 57.0 | - | - | 114.8 |
| 46 MDC 1976 | 58.4 | - | - | 108.4 |
| C 10 1923 | 58.5 | 489 | - | - |
| 45 MDC 1976 | 60.0 | - | - | 99.8 |
| 44 MDC 1976 | 61.9 | - | - | 104.7 |
| 43 MDC 1976 | 62.7 | - | - | 93.7 |
| DA 1 1934 | 65.1 | - | - | 81.3 |
| 42 MDC 1976 | 66.8 | - | - | 78.7 |
| Z 9 1923 | 68.4 | 308 | 383 | 75.3 |
| 41 MDC 1976 | 70.0 | - | - | 73.1 |
| Y 9 1923 | 71.4 | 317 | 389 | 71.6 |
| 40 MDC 1976 | 73.1 | - | - | 67.0 |
| E339 | 73.9 | - | - | - |
| USBPR 6802 | 74.7 | - | - | 62.6 |

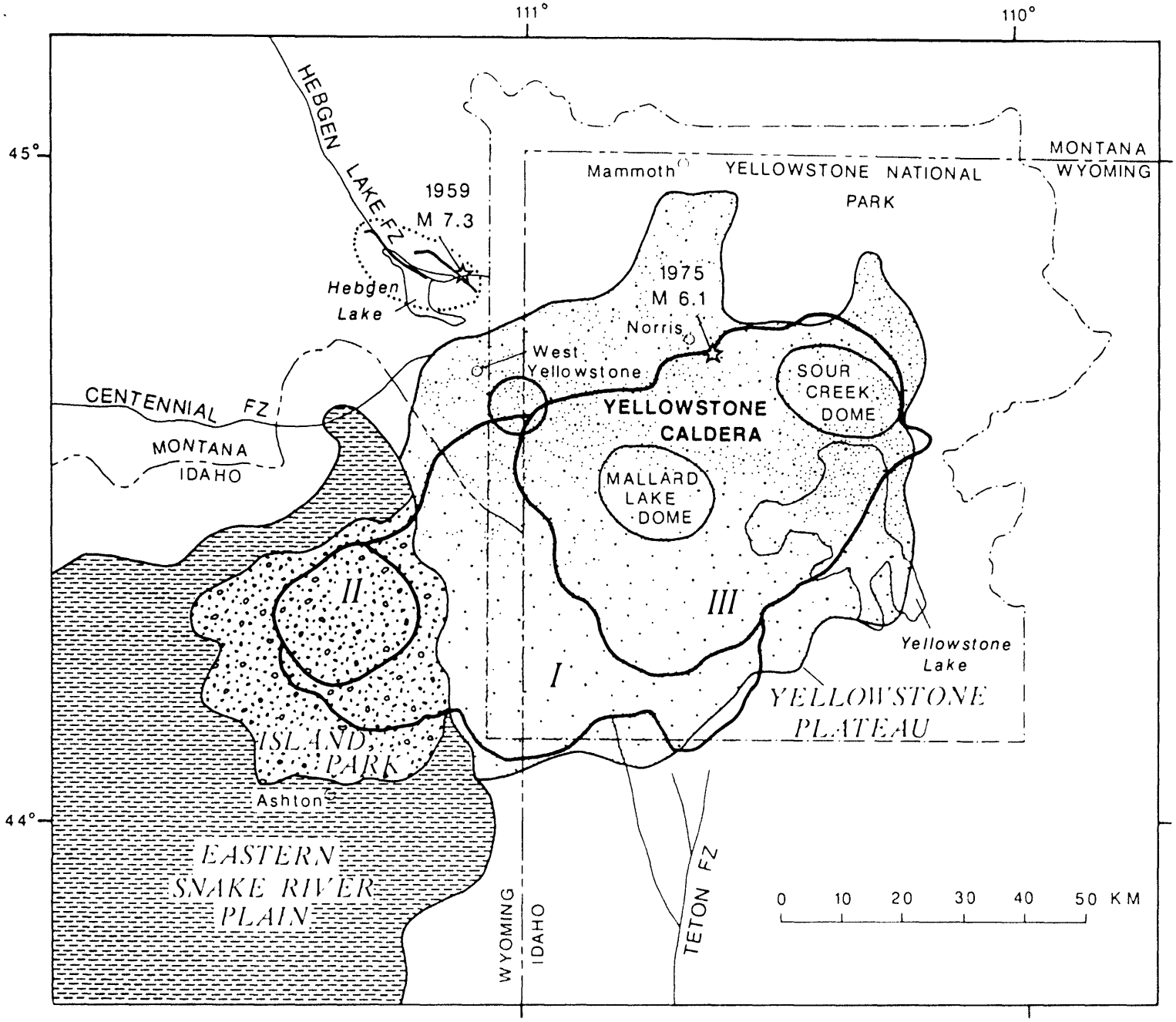


**FIGURE 1.** Eastern Snake River and Yellowstone Plateau with outlines of three calderas.

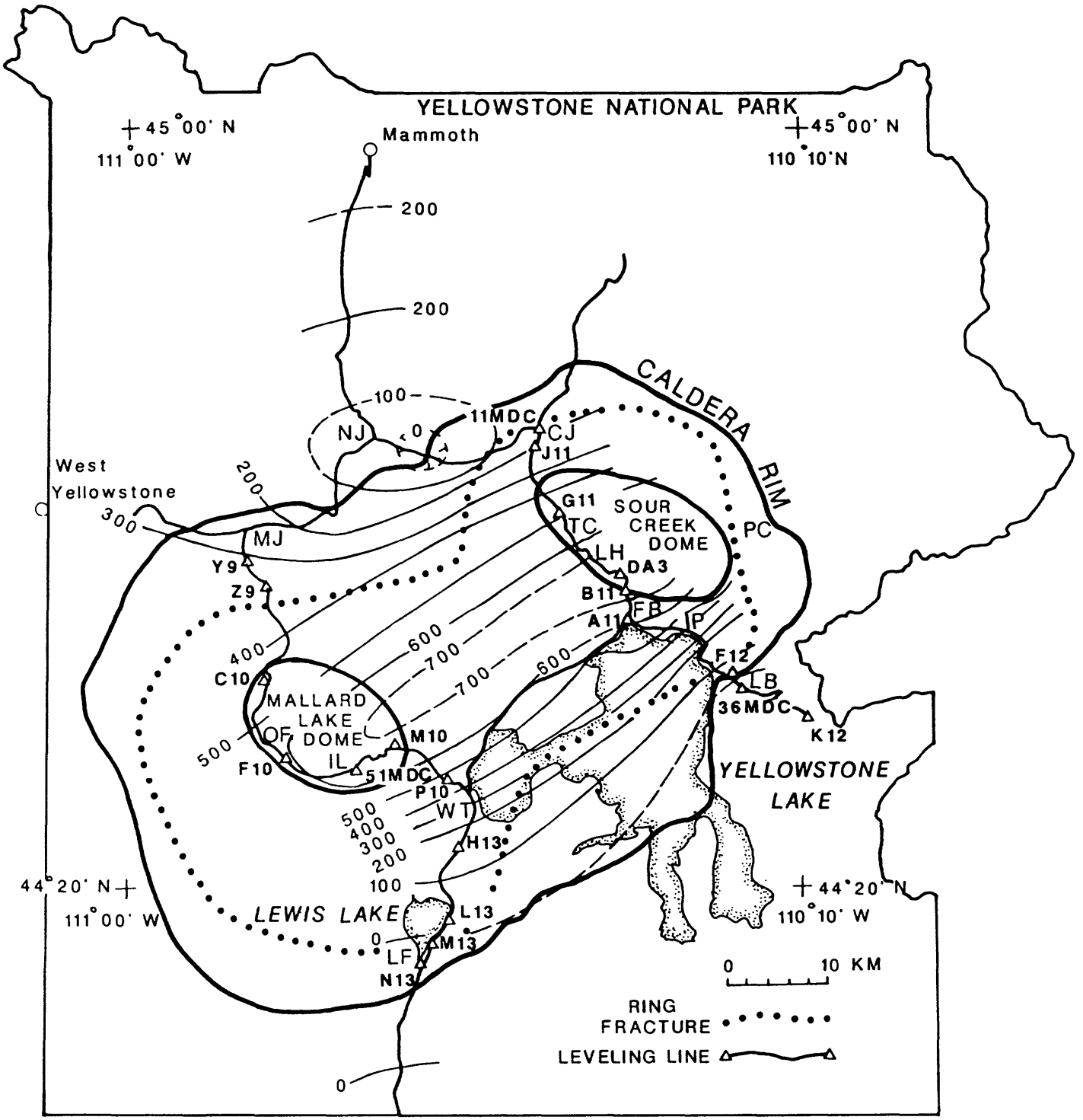


FIGURE 2. Yellowstone caldera and resurgent domes with localities and benchmarks.

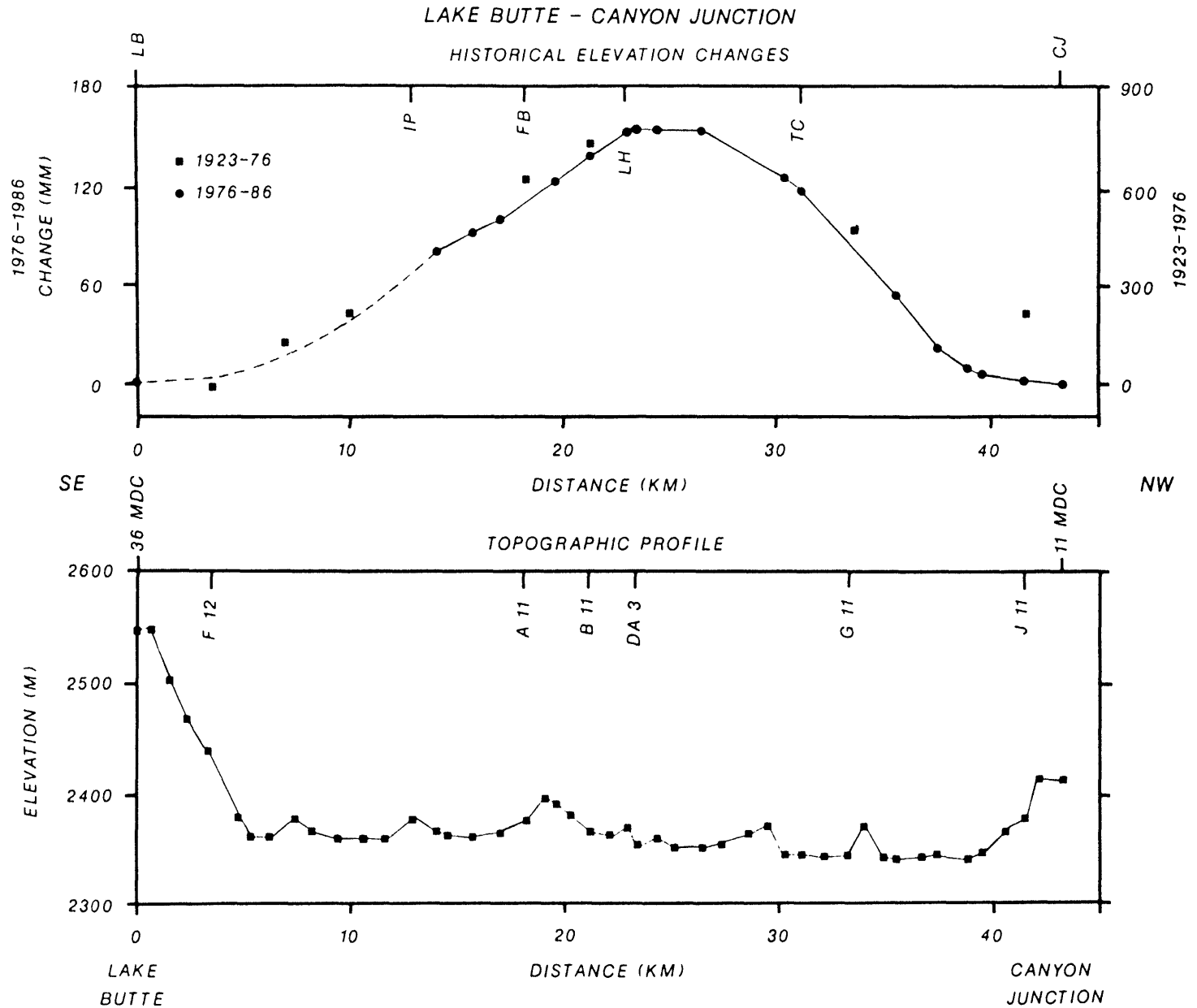


FIGURE 3. Historical elevation changes and topography from Lake Butte to Canyon Junction.

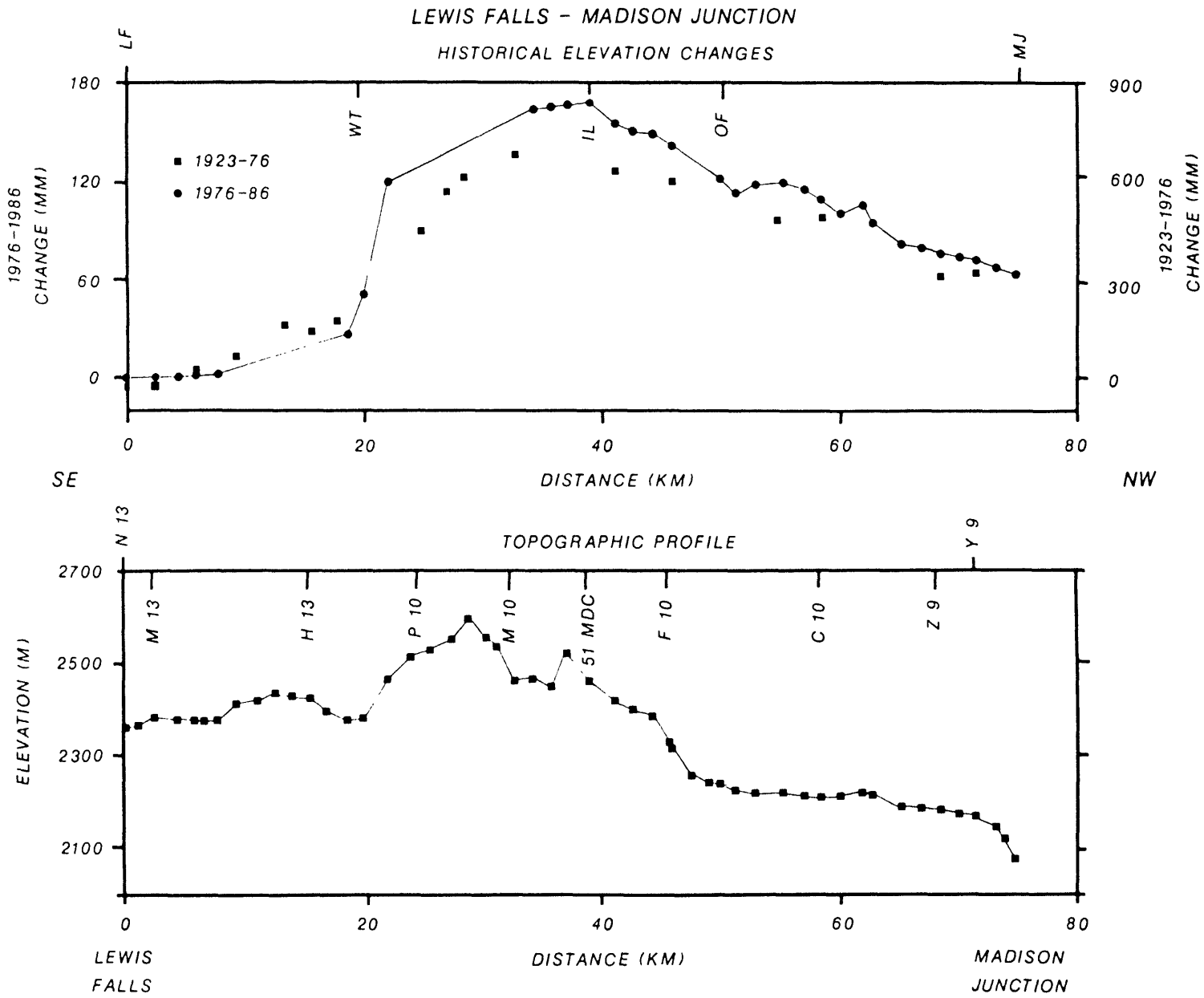


FIGURE 4. Historical elevation changes and topography, Lewis Falls to Madison Junction.

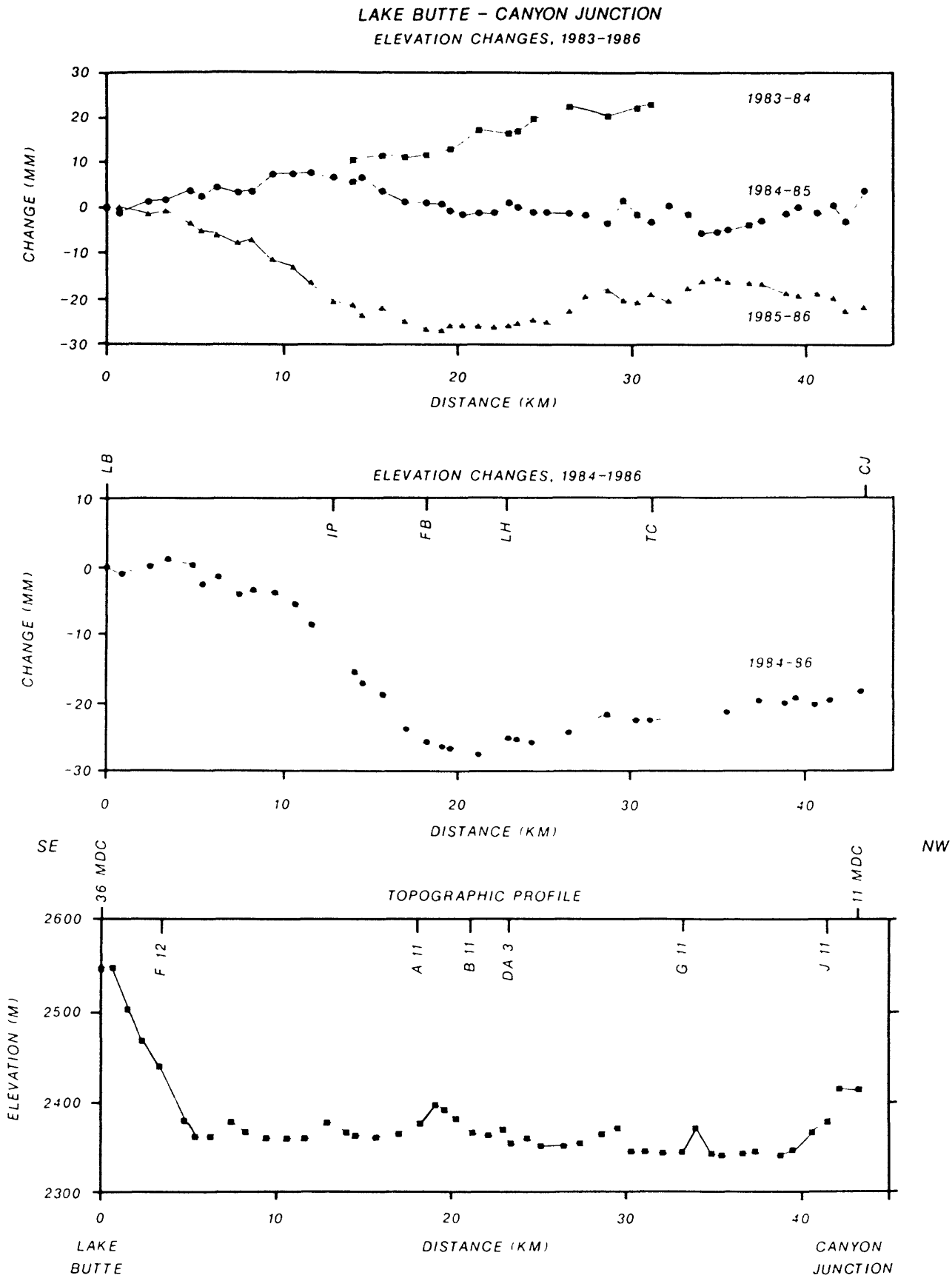


FIGURE 5. Elevation changes from 1983 to 1986 and topography, Lake Butte to Canyon Junction.

# LEWIS FALLS LEVEL LINE

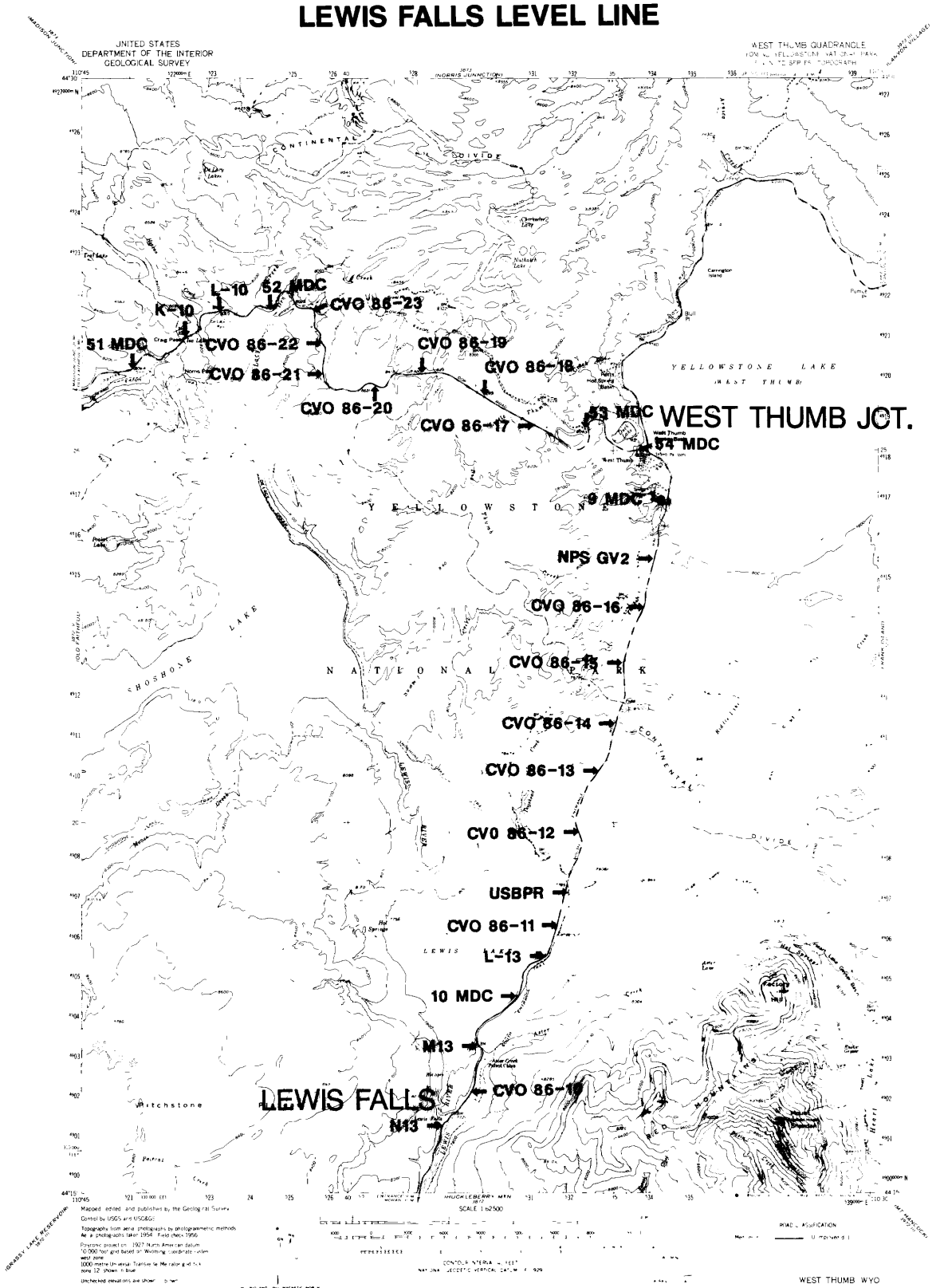


FIGURE 6. Southern segment of western leveling line between Lewis Falls and Madison Junction with benchmark locations.

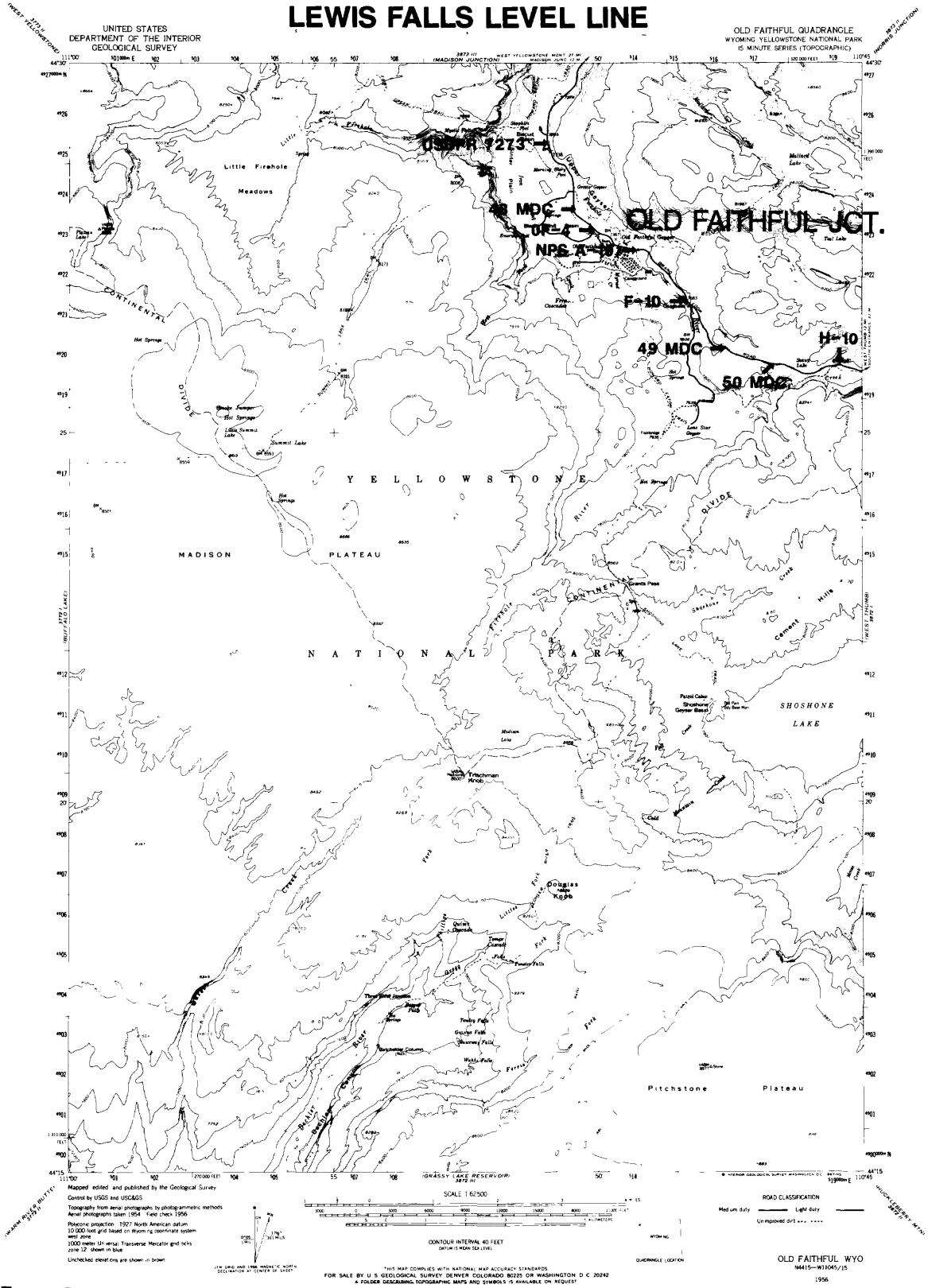


**FIGURE 7.** Central segment of western leveling line between Lewis Falls and Madison Junction with benchmark locations.

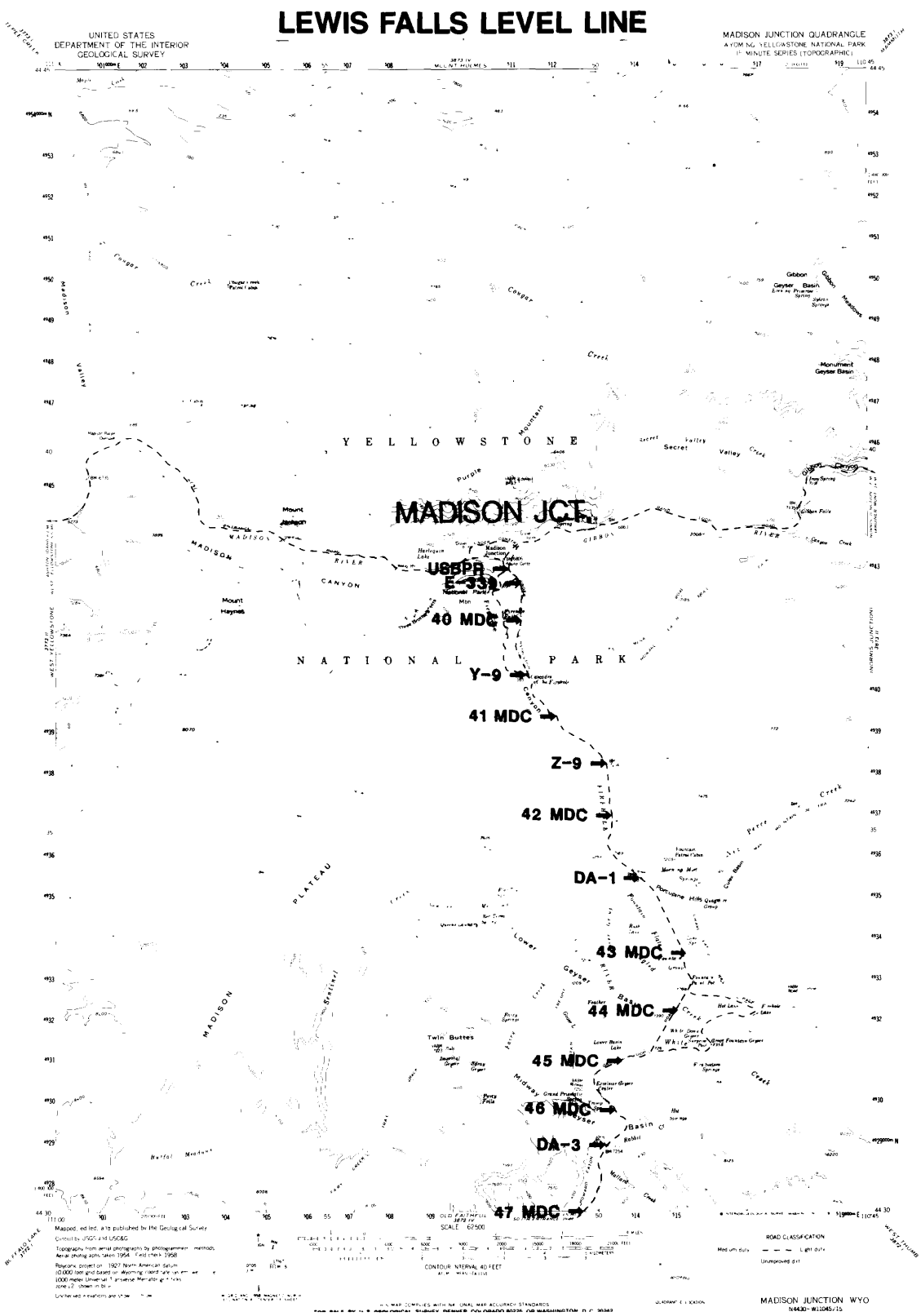


**FIGURE 8.** Northern segment of western leveling line between Lewis Falls and Madison Junction.

# YELLOWSTONE LEVEL LINE

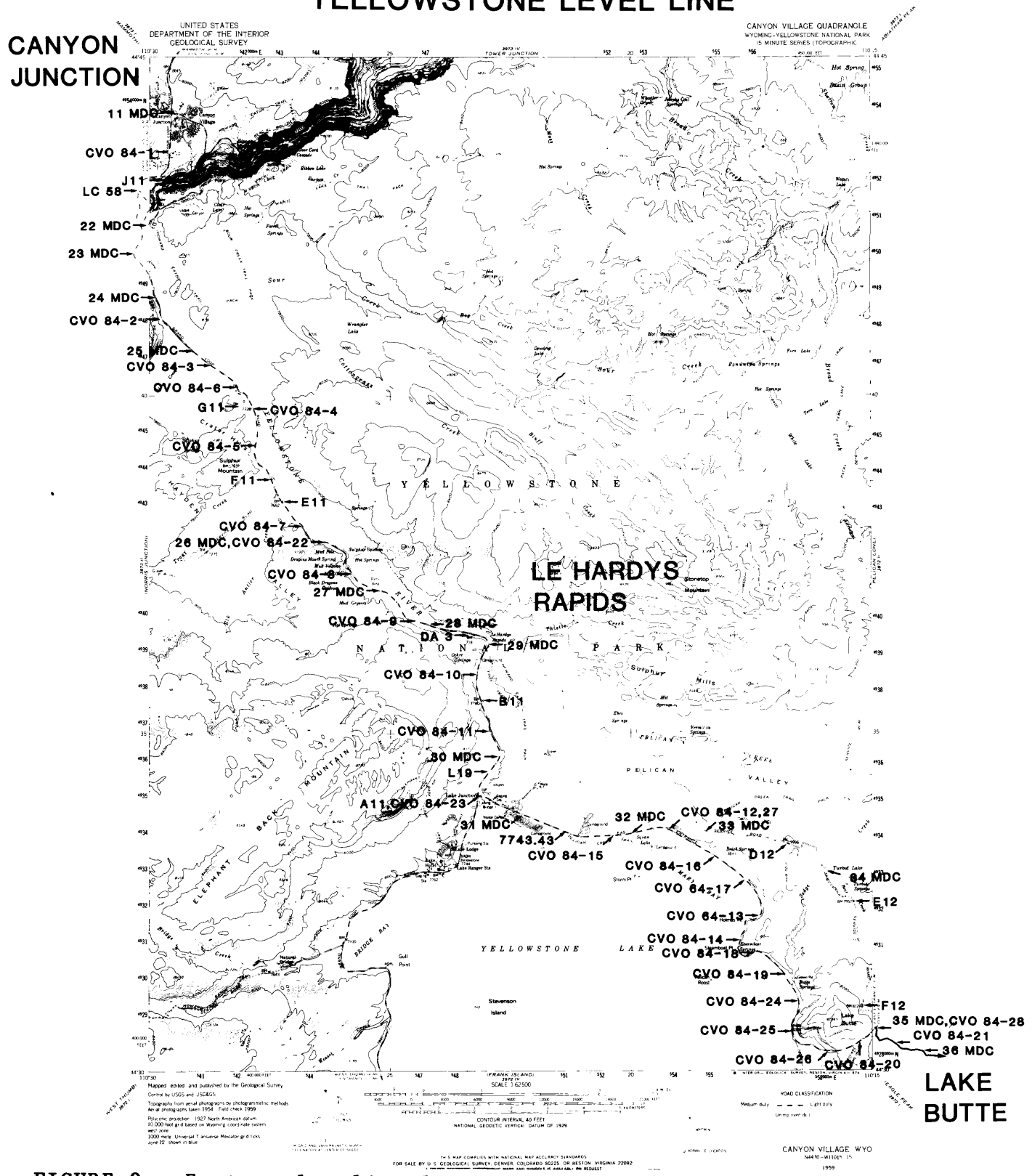


**FIGURE 9.** Eastern leveling line between Lake Butte and Canyon Junction with benchmark locations.

***APPENDIX***
***BENCHMARK DESCRIPTIONS***
***YELLOWSTONE NATIONAL PARK, WYOMING***
***LEWIS FALLS, WEST THUMB, OLD FAITHFUL JCT., MADISON JCT.***

The following pages describe benchmarks used for the level line from Lewis Falls to Madison Junction. Many of the benchmarks were installed in pervious surveys, notably in 1923 and 1975-1977. Fourteen new benchmarks were installed by the CVO crew along the paved road between Lewis Falls and Shoshone Lake to replace exisiting benchmarks along 2 abandoned service roads. All benchmarks described below are along paved National Park Service roads. The entire Lewis River level line is within the West Thumb, Old Faithful, and Madison Junction Quadrangles (15 minute series) (Fig. 6, 7 & 8)

The descriptions of the CVO series benchmarks are new; the older series descriptions were modified from Evoy and Smith (1979).

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|
| N13 (1923) | 12.4/20.0 | From West Thumb Jct. go 12.4 miles south along highway toward south entrance, 0.2 miles south of bridge over Lewis River, 9.8 meters west and 0.9 meter higher than centerline of highway. Benchmark is cemented on top of ledge on a 0.45 meter square boulder hidden amongst some small trees. |
| CVO 86-10 | 11.8/19.0 | From West Thumb Jct. go 11.8 miles south along highway toward south entrance. On the east side of gentle curve 70 meters north of roadcut in rock on west side of road, 9.8 meters east of centerline among small trees, the benchmark is cemented on a 1 meter boulder projecting 30 cm. |
| M13 (1923) | 10.9/17.6 | From West Thumb Jct. go 10.9 miles south along highway toward the south entrance, 35 meters south of entrance to Lewis Lake Campground, 18.9 meters west of centerline. The Benchmark is cemented on a 1 meter square boulder projecting 1 meter. |
| 10 MDC(1977) | 9.7/15.7 | From West Thumb Jct. go 9.7 miles south along highway toward the south entrance. On sweeping curve with turnout on west side, benchmark is cemented on the headwall of a culvert, 6 meters east of and 0.15 meter lower than centerline of highway, at north end of turnout. |

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

L-13(1923) 8.8/14.2 From West Thumb Jct. go 8.8 miles south along highway toward the south entrance, 0.4 miles north of turnout on westside, 11.8 meters west of centerline and 3 meters above shoreline of Lewis Lake. Benchmark is cemented on a 1 meter boulder projecting 30 cm.

CVO 86-11 8.3/13.4 From West Thumb Jct. go 8.3 miles south along highway toward south entrance. Benchmark is cemented on the south end of a culvert on the east side of road, 4.9 meters east of centerline.

USBPR 7.6/12.3 From West Thumb Jct. go 7.6 miles south (unstamped) along highway toward south entrance, 0.1 miles south of juntion with old highway. Benchmark is cemented on the east concrete headwall of bridge, 4.9 meters east of and 0.6 meter higher than centerline of highway.

CVO 86-12 6.6/10.7 From West Thumb Jct. go 6.6 miles south along highway toward south entrance. Benchmark is cemented on the north end of a culvert, 6.5 meters east of centerline and 1.5 meters below road surface.

CVO 86-13 5.5/8.9 From West Thumb Jct. go 5.5 miles south along highway toward south entrance. Benchmark is cemented on the north end of a culvert, 5.8 meters west of centerline of highway.

CVO 86-14 4.6/7.4 From West Thumb Jct. go 4.6 miles south along highway toward south entrance. Benchmark is cemented on the south end of a culvert, 6.8 meters west of centerline of highway and 0.5 meter below road level.

CVO 86-15 3.6/5.9 From West Thumb Jct. go 3.6 miles south along highway toward south entrance. Benchmark is cemented on the north end of a culvert, 6.3 meters east of centerline of highway and 1.5 meters below road level (may be buried by fill).

CVO 86-16 2.7/4.4 From West Thumb Jct. go 2.7 miles south along highway toward south entrance. Benchmark is cemented on the north end of a culvert, 6.9 meters west of centerline and 1.5 meters below road level.

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

NPS GV2(1977) 1.9/3.1 From West Thumb Jct. go 1.9 miles south along highway toward south entrance, 11 meters west of centerline of southbound lane, 5.5 meters NW of junction sign. Benchmark is set in concrete within a 15 cm PVC pipe projecting 5 cm.

9 MDC(1977) 0.8/1.3 From West Thumb Jct. go 0.8 miles south along highway toward south entrance to bridge over Big Thumb Creek. Benchmark is cemented on the northwest retaining wall of bridge, 4.9 meters southwest and 0.6 meter higher than centerline of highway.

54 MDC(1976) 0/0 At West Thumb Jct. behind wooden highway sign, directly opposite of where lake Jct road T's into south entrance road. The benchmark is 19.2 meters west of centerline of highway. It is set on a 1.5 cm copper coated rod encased in a 15 cm pipe.

53 MDC(1976) 1.3/2.1 From West Thumb Jct. go 1.2 miles north toward Old Faithful Jct. Benchmark is at T junction of main road and gravel road, 7.6 meters west of centerline of main highway and 1.2 meters lower than surface of road. The benchmark is cemented on top of culvert headwall.

CVO 86-17 2.5/4.0 From West Thumb Jct. go 2.5 miles north toward Old Faithful Jct. Benchmark is 9.4 meters north of centerline on a 1 meter boulder projecting 30 cm, 5 meters east of culvert on north side of the road, and 1 meter below road level.

CVO 86-18 3.6/5.8 From West Thumb Jct. go 3.6 miles north toward Old Faithful Jct. Benchmark is on the north side of road cemented on the east end of a culvert, 1 meter below road level.

CVO 86-19 4.7/7.6 From West Thumb Jct. go 4.7 miles north toward Old Faithful Jct. Benchmark is cemented on the west end of a culvert on the north side of road at a small meadow, 7 meters north of centerline and 2 meters below road level.

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

CVO 86-20 5.6/9.1 From West Thumb Jct. go 5.6 miles north toward Old Faithful Jct. Benchmark is cemented on the west end of a 1 meter boulder projecting 30 cm, 7.6 meters north of centerline of highway. It is on the west end of a large roadcut.

CVO 86-21 6.6/10.7 From West Thumb Jct. go 6.6 miles north toward Old Faithful Jct. Benchmark is cemented on a 3 meter boulder by small roadcut on the north side of the road. It is 7.9 meters north of centerline and 1.5 meters above road level.

CVO 86-22 7.2/11.6 From West Thumb jct. go 7.2 miles north toward Old Faithful Jct. Benchmark is cemented on the west end of a culvert on south side of the road, 6.5 meters south of centerline and 1 meter below road level. May be covered by soil.

CVO 86-23 8.5/13.8 From West Thumb Jct. go 8.5 miles north toward Old Faithful Jct. Benchmark is cemented on a 1 meter boulder projecting 0.5 meter, 7.3 meters east of centerline and 5 meters north of culvert by small stream.

52 MDC(1976) 9.5/15.4 From West Thumb Jct. go 9.5 miles north toward Old Faithful Jct. to Shoshone Lake turnout on south side of road. The benchmark is near the center of turnout just north of "Shoshone Lake" sign. It is set on a 1.5 cm copper-coated rod encased in a 15 cm pipe.

L-10-1937 10.5/16.9 From West Thumb Jct. go 10.5 miles north toward Old Faithful Jct. By east edge of Heron Creek 7.6 meters north of centerline of highway, 0.6 meter higher than road level. Benchmark is cemented on a concrete post projecting 0.3 meter.

K-10-1936 11.4/18.4 From West Thumb Jct. go 11.4 miles north toward Old Faithful jct. Benchmark is near the east end of parking lot on the north side of the highway; 3.0 meters east of Isa Lake (right on continental Divide). Benchmark is set on a concrete post projecting 45 cm.

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

51 MDC(1976) 12.6/20.3 From West Thumb Jct. go 12.6 miles north toward Old Faithful Jct. (6.8 miles south of OFJ). Benchmark is at parking area for trailhead, 20.7 meters south of trail sign "DIVIDE LOOKOUT TRAIL". It is about 1.0 meter higher than highway, set on a 1.5 cm copper-coated rod encased in a 15 cm drainpipe.

H-10-1923 14.0/22.5 From West Thumb Jct. go 14.0 miles north toward Old Faithful Jct. (5.4 miles south of OFJ). Benchmark is just before turnout on south side of highway, near culvert under road. It is 30.5 meters east of the culvert and 11.9 meters north of centerline of highway, 0.3 meter lower than road level cemented on a boulder.

50 MDC(1976) 14.9/24.0 From West Thumb Jct. go 14.9 miles north toward Old Faithful Jct. (4.5 miles south of OFJ). Benchmark is near turnout on north side of highway, 30.0 meters east of the west end of the turnout, 0.3 meter higher than road level. It is in the center of a clear spot among trees, set on a 1.5 cm copper-coated rod encased in a 15 cm drainpipe.

49 MDC(1976) 15.9/25.6 From West Thumb Jct go 15.9 miles north toward Old Faithful Jct. (3.5 miles south of OFJ). Benchmark is near a point where the highway runs between two cuts (rock cut on north side and mounded dirt on south side); about 22.9 meters west of east end of mounded cut. It is 15.8 meters south of centerline, close to road level, cemented on top of outcrop at edge of a 2.1 meter dropoff just south of mark.

F-10-1923 16.9/27.2 From West Thumb Jct. go 16.9 miles north toward Old Faithful Jct. (2.5 miles south of OFJ). Benchmark is at the Kepler Cascade turnout on the south side of the highway. It is in the center of turn-out, 1.2 meters south of asphalt walkway, set on a concrete post projecting 36 cm.

NPS A-19(1976) 17.9/28.8From West Thumb Jct. go 17.9 miles north toward Old Faithul Jct. (1.5 miles south of OFJ). Benchmark is on the south side of the bridge over the Firehole River cemented on the east end of walkway.

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

OF-4(1976) 19.4/31.2 From West Thumb Jct. go 19.4 miles north toward Old Faithful Jct. Benchmark is at the southeast corner of the Old Faithful Junction overpass, cemented on the south end of the east concrete walkway over the bridge, about 0.3 meter higher than road level.

48 MDC(1976) 0.9/1.5 From Old Faithful Jct. go 0.9 miles north toward Madison Jct. Benchmark is 12.5 meters northeast of centerline and 1.0 meter lower than highway. It is cemented on the top of a lava outcrop projecting about 3 cm. The outcrop is about 6.1 meters south of a culvert pipe that runs under the highway.

USBPR 7273 2.0/3.3 From Old Faithful Jct. go 2.0 miles north toward Madison Jct. Benchmark is just south of Biscut Basin, cemented on the southwest corner of bridge over the "Fire-hole River". It is 0.3 meter higher than road level, cemented on the walkway.

47 MDC(1976) 3.4/5.5 From Old Faithful Jct. go 3.4 miles north toward Madison Jct. Benchmark is at section of highway that runs north-south between two curves, 6.4 meters west of centerline of road. It is cemented on a culvert about 3 cm below road level.

DA-3(1935) 4.5/7.2 . From Old Faithful Jct. go 4.5 miles north toward Madison Jct. Benchmark is at T-road west-northwest, about 12.2 meters northwest of center of the T-road jct. It is 15 cm higher than road level, cemented on a concrete post projecting 45 cm.

46 MDC(1976) 5.4/8.7 From Old Faithful Jct. go 5.4 miles north toward Madison Jct. Benchmark is cemented on a culvert located under the road at a horseshoe-shaped turnout on the southwest side of the highway. It is 5.8 meters southwest of centerline of the highway at about road level.

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

45 MDC(1976) 6.4/10.3 From Old Faithful Jct. go 6.4 miles north toward Madison Jct. Benchmark is at T-road southeast of picnic area, 13.7 meters southeast of centerline of main highway and 12.8 meters southwest of centerline of T-road. It is 1.0 meter lower than road level, set on a 1.5 cm copper-coated rod encased in a 15 cm drainpipe.

44 MDC(1976) 7.5/12.1 From Old Faithful Jct. go 7.5 miles north toward Madison Jct. At top of small rise in middle of long straight stretch of highway, the benchmark is near center of turnout on east side of road, 10.0 meters east of centerline and 0.3 meter lower than road level. It is in the center of a 3.0 meter circular clear spot surrounded by dying trees, set on a 1.5 cm copper-coated rod encased in a 15 cm drainpipe (this benchmark was under water Sept. 1986).

43 MDC(1976) 8.3/13.4 From Old Faithful Jct. go 8.3 miles north toward Madison Jct. Benchmark is near a point where the highway passes through a cut on the east side of the road, 12.2 meters east of centerline and 1.8 meters higher than road level. It is cemented on a boulder that is buried on a sidehill at the south side of the cut.

DA-1(1934) 9.8/15.8 From Old Faithful Jct. go 9.8 miles north toward Madison Jct (5.9 miles south of MJ). Benchmark is cemented on top of the northeast abutment of bridge over Nez Perce Creek.

42 MDC 10.8/17.4 From Old Faithful Jct. go 10.8 miles north toward Madison Jct. (4.9 miles south of MJ). Benchmark is at a horseshoe shaped turnout on west side of road, 21.3 meters north of turnout, 16.7 meters west of centerline of highway and 1.0 m higher than road level. It is cemented on the east side of a dome-shaped boulder projecting 1.1 meter.

Z-9 1923 11.8/19.0 From Old Faithful Jct. go 11.8 miles north toward Madison Jct. (3.9 miles south of MJ). Benchmark is 58.8 meters north of Y-road northeast intersection, 9.1 meters east of centerline of main highway, at about road level. It is set on a concrete post projecting 18 cm.

| NAME | DISTANCE (mi/km) | DESCRIPTION |
|---|---|---|

41 MDC(1976) 12.8/20.6 From Old Faithful Jct. go 12.8 miles north toward Madison Jct. (2.9 miles south of MJ). Benchmark is on a large rock boulder by a gravel turnout on the west side of the road, 12.5 meters west of centerline and 1.8 meters higher than road level. It is cemented on top and near the center of the large boulder.

Y-9 1923 13.7/22.1 From Old Faithful Jct. go 13.7 miles north toward Madison Jct. (2.0 miles south of MJ). Benchmark is 52.7 meters west of center of T-road jct. at Firehole Canyon Drive exit road, 61.0 meters north of Firehole River Cascade, 2.1 meters east of the east bank of Firehole River and 1.5 meter lower than highway intersection. It is set on a boulder projecting 0.1 meter.

40 MDC(1976) 14.7/23.7 From Old Faithful Jct. go 14.7 miles north toward Madison Jct. (1.0 mile south of MJ). Benchmark is at north end of turnout on west side of highway, 21.9 meters west of and across drain from centerline of highway, on west sidehill of drain, about 30 cm higher than road level. It is cemented on a boulder projecting 30 cm.

E-339 15.2/24.5 From Old Faitful Jct. go about 15.3 miles north toward Madison Jct. Benchmark is set on bedrock on the west side of the road, approximately 0.7 meter higher than road level and about 15.2 meters south of a gravel service road.

USBPR 15.7/25.3 From Old Faithful Jct go 15.7 miles north toward Madison Jct. (just south of the Jct.). Benchmark is on the north end of the east abutment of the bridge over the Gibbon river.

## FIGURE CAPTIONS

Figure 1. Eastern Snake River Plain and Yellowstone Plateau with outlines of three calderas: I, 2.0 m.y.; II 1.3 m.y.; and III, 0.6 m.y. stars, epicenters of 1959 M 7.3 Hebgen Lake earthquake and 1975 M 6.1 Yellowstone Park earthquake; dotted line, area of 1959 ground rupture; open circle, area of 1985-87 earthquake swarm.

Figure 2. Yellowstone caldera and resurgent domes with localities and benchmarks (open triangles) mentioned in text. Also shown, 1923-76 uplift contours in millimeters from pelton and smith (1982). Localities (Lake Butte to Canyon Junction): LB, Lake Butte; IP, Indian Pond; FB, Fishing Bridge; LH, LeHardy Rapids; TC, Trout Creek; CJ, Canyon Junction; (lewis Falls to Madison Junction): LF, Lewis Falls; WT, West thumb; IL, Isa Lake; OF, Old Faithful; MJ, Madison Junction; (other): NJ, Norris Junction; PC, Pelican Cone. Benchmarks (Lake Butte to Canyon Junction): K 12 1923, 36 MDC 1976, F 12 1923, All 1923, B 11 1923, DA 3 1934, G 11 1923, J 11 1923, 11 MDC 1976; (Lewis Falls to Madison Junction): N13 1923, M 13 1923, H 13 1923; P 10 1923, M10 1923, 51 MDC 1976, F 10 1923, C 10 1923, Z 9 1923, Y 9 1923.

FIGURE 3. Historical elevation changes and topography from Lake Butte to Canyon Junction. Note different vertical scales for the 1923-76 and 1976-86 data. The 1923-76 changes are relative to Benchmark K 12 1923, and 1976-86 changes relative to 36 MDC 1976. See Figure 2 for locations.

FIGURE 4. Historical elevation changes and topography, Lewis Falls to Madison Junction. Note different vertical scale for the 1923-76 and 1976-86 data. The 1923-76 changes are relative to benchmark K 12 1923, 1976-86 changes relative to N12 1923. See Figure 2 for Locations.

FIGURE 5. Elevation changes from 1983-1986 and topography, Lake Butte to Canyon Junction. Top, annual changes; middle, net changes from 1984 to 1986; bottom, topographic profile. See Figure 2 for locations.

FIGURE 6. Southern segment of western leveling line between Lewis Falls and Madison Junction. Arrows indicate locations of benchmarks.

FIGURE 7. Central segment of western leveling line between Lewis Falls and Madison Junction. Arrows indicate locations of benchmarks.

FIGURE 8. Northern segment of western leveling line between Lewis Falls and Madison Junction. Arrows indicate locations of benchmarks.

FIGURE 9. Eastern leveling line between Lake Butte and Canyon Junction. Arrows indicate locations of benchmarks.